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Supplementary appendix

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Appendix

Preparedness and vulnerability of African countries against importations of COVID-19: a modelling study

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Risk of case importation

The risk of importation of COVID-19 cases in a country outside China, α, from a city in China i, is based on:

- the travel flux from i, n_i;
- the cumulated incidence in i, e_i (assumed to be homogeneous within each province);
- the probability of traveling from i to α, conditioned on traveling internationally from i, $A_{i\alpha}$ (by construction, $\sum_\alpha A_{i\alpha} = 1$).

We define risk flow from i to α as the matrix

$$r_{i\alpha} = \frac{e_i n_i A_{i\alpha}}{\sum_j e_j n_j}.$$

The risk of case importation to α from whatever origin in China is then

$$R_\alpha = \sum_i r_{i\alpha}.$$

This risk is normalized so that $\sum_\alpha R_\alpha = 1$.

Exposure analysis

For each African country, α, we define the exposure vector, $v^{(\alpha)}$, whose entry $v_i^{(\alpha)}$ encodes the contribution of city i in China to the importation risk R_α:

$$v_i^{(\alpha)} = \frac{r_{i,\alpha}}{R_\alpha}$$

By construction these entries sum to one, $\sum_i v_i^{(\alpha)} = 1$. Therefore, we can use entropy-related metrics to quantify the similarity between the exposure patterns of two different destination countries, α and β. Specifically, once defined the entropy of $v^{(\alpha)}$ as

$S\left(v^{(\alpha)}\right) = -\sum_i v_i^{(\alpha)} \log v_i^{(\alpha)}$,

we used the Jensen-Shannon divergence between the two vectors, $v^{(\alpha)}$, and $v^{(\beta)}$, defined as

$\Delta_{\alpha\beta} = S\left(\frac{v^{(\alpha)}+v^{(\beta)}}{2}\right) - \frac{S\left(v^{(\alpha)}\right)+S\left(v^{(\beta)}\right)}{2}$,

We then apply agglomerative clustering (linkage complete) to identify clusters of countries with similar exposure patterns.

Sensitivity analysis

The risk computation is based on the hypothesis that infectious travelers out of China will depart from airports located within the province of residence. However, this may not be the case in some situations. We relaxed this hypothesis by associating to Beijing and Shanghai airports the overall incidence of their municipality and of neighboring provinces. Specifically, overall incidence is computed by dividing the total number of cases in the municipality and its neighbors by the total population of the area.

Figure S1 shows that the risk obtained with the modified definition of incidence is highly correlated with baseline values.

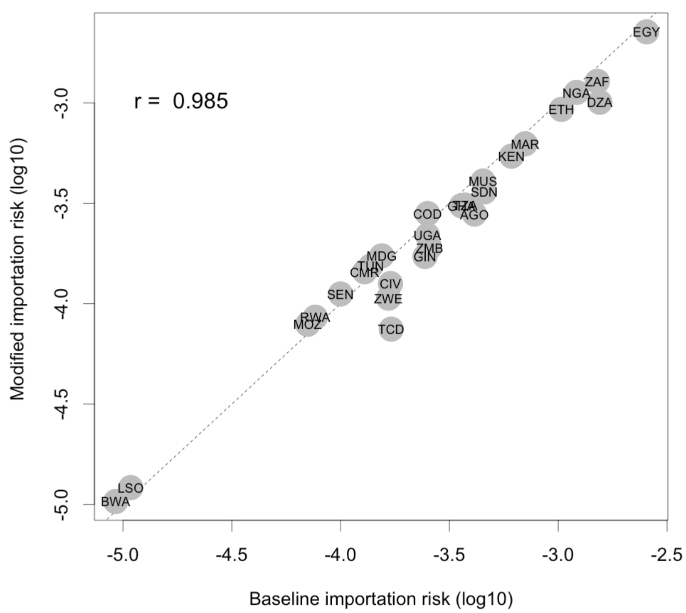

Figure S1 Scatter plot of the modified importation risk vs. baseline risk.

Selection of preparedness and vulnerability metrics

A preliminary analysis of indicators of preparedness and vulnerability was carried out using six indicators.

The WHO Monitoring and Evaluation Framework produces two indicators that were particularly relevant to quantify the preparedness: the mandatory State Parties self-assessment Annual Reporting (SPAR), and the voluntary Joint External Evaluation (JEE). The SPAR includes data on all countries annually, and the JEE includes data on countries that have been through the joint evaluation process on a voluntary basis between 2016 and 2019.

The SPAR data [1] contains a total of 20 indicator scores collected annually and extracted for 2018 in all countries in Africa organized and grouped according to capacities (number between brackets is the number of indicators per capacity): Legislation (2), IHR Coordination (2), Zoonoses (1), Food safety (1), Laboratory (3), Surveillance (2), Human resource (1), National health emergency framework (3), Health service provision (3), Communication (1), Points of Entry (2), Chemical events (1) and Radiation emergency (1).

The JEE data [2] contains a total of 49 indicators collected between 2016 and 2019 in 43 countries in Africa, organized in the following technical areas (number between brackets is the number of indicators per technical area): Legislation (2), Coordination (1), Antimicrobial resistance (4), Zoonoses (3), Food safety (1), Bio-safety and Bio-security (2), Immunization (2), Laboratory (4), Surveillance (4), Reporting (2), Human resources (3), Emergency preparedness (2), Emergency response operation (4), Linking public health and security (1), Medical countermeasures and personal deployment (2), Risk communication (6), Points of entry (2), Chemical events (2) and Radiation emergency (2).

From both the SPAR and JEE data, we extracted two indicators each: one to quantify the overall capacity of the country to deal with an emerging epidemics, and one focusing more specifically on the detection capacity.

For the broad capacity with the SPAR data (SPAR1), we estimated the average score of all capacities except those of the groups Zoonoses, Food safety, Chemical events and Radiation emergency. For the broad capacity with the JEE data (JEE1), we estimated the average score of all technical areas except Antimicrobial resistance, Zoonotic diseases, Food safety, Chemical events and Radiation emergencies.

For the detection capacity with the SPAR data (SPAR2), we averaged the score of the capacities: Laboratory, Surveillance, Points of Entry. For the detection capacity with the JEE data (JEE2), we averaged the score of the technical areas: National laboratory system, Surveillance and Point of entry.

As indicators of overall vulnerability, we extracted the Infectious Disease Vulnerability Index (IDVI) [3], and the INFORM Epidemic Risk Index (ERI) [4].

All metrics were rescaled from 0-100 from the lowest to the highest capacity, or, conversely from the highest to the lowest vulnerability.

The multivariate analysis (Figure S2) showed a very high correlation between SPAR1 & SPAR2 (r = 0.895), JEE1 & JEE2 (r = 0.854) and between IERI and IDVI (r = 0.858). Between the four indicators of capacity (SPAR1, SPAR2, JEE1, JEE2) and the two indicators of vulnerability (IDVI & ERI), the lowest correlation was found between the SPAR1 and IDVI indicators, (r = 0.459), with a lower correlation than SPAR1 and ERI (r = 0.473). The principal component analysis bi-plot (showing 88.63% of the variability) visualizes these trends and highlights that SPAR1 and IDVI as the least redundant index.

Given the availability of the SPAR data in all countries (vs. only 43 countries for the JEE data), the very high correlation between SPAR1 and SPAR2, the very high correlation between IDVI and ERI, and the lowest correlation between SPAR1 and IDVI, we selected SPAR1 and IDVI as the most complementary measures to capture the overall preparedness capacity in one hand, and the overall disease vulnerability in the other hand.

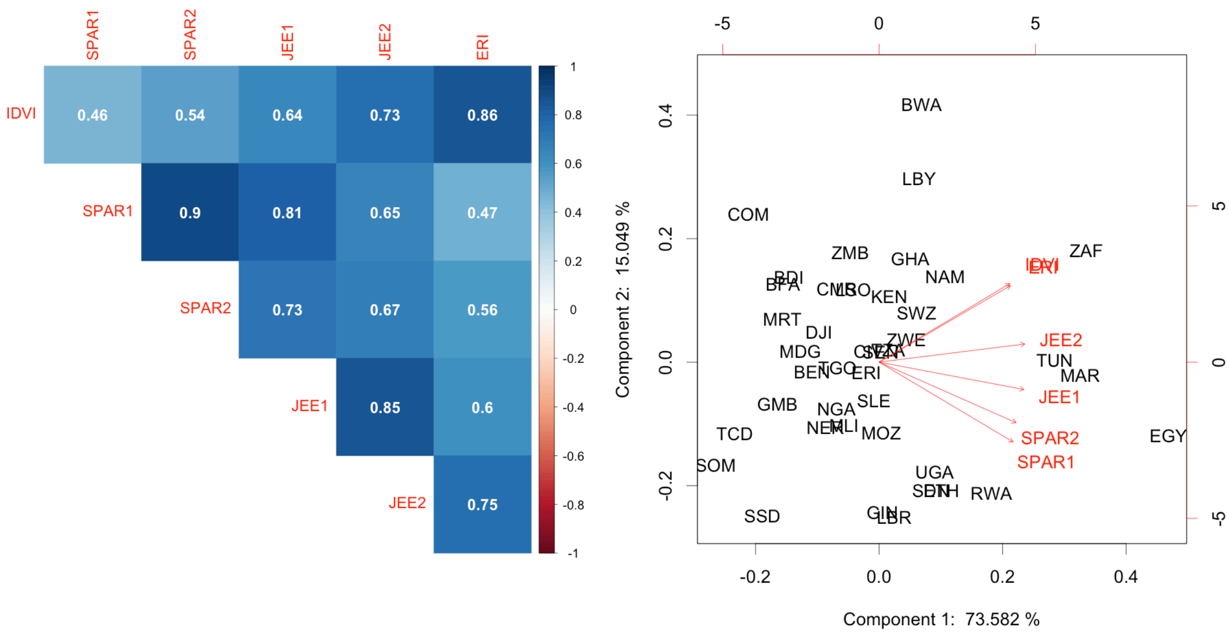

Figure S2 Correlogram (left) and principal component analysis bi-plot (right) of the different indicators of preparedness and vulnerability.

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